AN EVENT-RELATED POTENTIAL STUDY OF KANJI CHARACTER DISCRIMINATION AND PERCEPTION IN THE BRAIN

Hiroshi Abe* and Minoru Nakayama†
*Graduate School of Decision Science and Technology, Tokyo Institute of Technology, Tokyo, 152-8552, Japan
E-mail: abe@nk.cradle.titech.ac.jp
†CRADLE, Tokyo Institute of Technology, Tokyo, 152-8552, Japan
Tel: +81-3-5734-3234, E-mail: nakayama@cradle.titech.ac.jp

***Abstract*— The frontal area in the brain is known to be involved in behavioral judgment. According to event-related potential (ERP) studies about visual processing and language processing, we hypothesized that, in Kanji (also called Chinese characters) character discrimination, (1) the frontal ERP waveforms reflect the discrimination process from 200-250ms after stimulus onset and that (2) the discrimination process in the frontal ERP waveforms coincidentally appears with that in the left posterior temporal ERP waveform, which seems to be related to Kanji lexical access. To examine these hypotheses, we analyzed ERPs while performing a Kanji discrimination task where subjects had to discriminate between Kanji and other characters. As the results, (1) the frontal ERP waveforms showed significant differences from 217ms after stimulus onset between different character types. (2) The left posterior temporal ERP waveforms also showed a significant difference from 223ms. These results supported our hypotheses. Therefore we suggest that, in Kanji character discrimination, lexical access for Kanji characters in the left posterior temporal area is related to the discrimination process in the frontal area. Also, we found that the frontal ERP waveforms around 160ms after stimulus onset may be related to Kanji perception or a discrimination process based on the perception.**

***Index Terms*— Kanji, Character discrimination, Event-related Potential, Perception**

I. Introduction

The frontal area in the brain is known to be involved in behavioral judgment in a given circumstance [1]. For example, when subjects were asked to give or not give a response depending on a situation, event-related potentials (ERPs), recorded from electrodes on the frontal area showed clear amplitude differences between trials when subjects responded and when subjects didn't respond, which suggests that the frontal ERP waveforms are related to the judgment [2].

Using this nature of ERPs, several studies [3], [4] reported that, even when requiring a demanding visual processing, the brain can decide a behavioral judgment from around 150ms after stimulus onset. For example, in such a study [3], the subjects reported if a natural image presented contains animals or not by responding or not responding respectively. The images were new to the subjects and not repeatedly presented. For each animal image, the subjects didn't know the kind, number, size, and location of the animals a priori. Although such a demanding task, the frontal ERP waveforms showed clear amplitude differences from around 150ms after stimulus onset when a presented image contained animals and when it didn't, reflecting the judgment in the brain. Such an animal detection may be a special case, because that function may be acquired during evolution for biological advantages to survive. However, it is shown that artificial objects such as cars are similary quickly processed [4], [5], which suggests a possibility that such a rapid visual processing is common for visual discrimination.

In this paper, we examined if it is true when language information is involved, because it is suggested that, in language processing, different mechanisms are involved in addition to visual analysis. In word recognition, it is generally assumed that words are processed in the two stages: visual analysis, and semantic and phonological retrieval [6]. Firstly the form of a presented word is visually recognized, and then the meaning and sound of the word are retrieved. The latter stage is also called lexical access. It is suggested that lexical access for words occurs 200-250ms after stimulus onset [7], [8]

Kanji (also called Chinese characters) is a Japanese logogram system. Kanji characters have at least three different characteristics from European alphabets. First, those visual forms are relatively complex (ex. see Fig.1). Second, a single Kanji character has one or more sounds to be pronounced and often has a meaning by itself. Third, there are many Kanji characters (about 2,000 Kanji characters are commonly used in Japanese). An ERP study suggests that a single Kanji character is processed like a word [9], probably due to these characteristics. Therefore, in Kanji character discrimination, we hypothesized that the frontal ERP waveforms reflect the discrimination process from 200-250ms after stimulus onset, differently from the results in visual scene analysis [3], [4].

To examine this hypothesis, we recorded and analyzed subjects'ERP waveforms while performing a kanji discrimination task. In this task, the subject had to discriminate Kanji characters from Hiragana characters. As a control, we used Hiragana (a Japanese phonogram system) characters, because Hiragana characters are easily visually discriminable from Kanji characters, and have different characteristics from

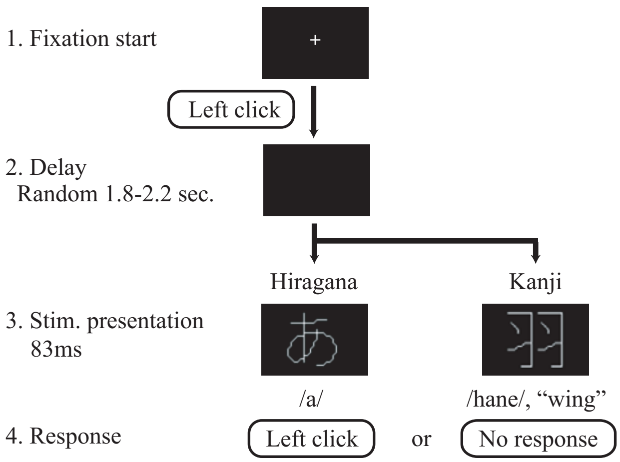

Fig. 1. Experimental task

Kanji characters (a single Hiragana character has only one sound and the number is small, 46 characters). Also because Hiragana characters can be classified into the same category (Japanese characters), we can attribute differences in ERPs to differences in the restricted category, i.e. Japanese characters. But if we use another stimulus belonging to another category, its interpretation is often difficult (ex. Japanese characters vs. object images).

If the hypothesis is true, the result suggests that difference in the frontal ERP waveforms may be due to lexical access for characters. Therefore, in that case, we further hypothesized that the difference in the frontal ERP waveforms coincidentally appears with that in the left posterior temporal ERP waveform, which seems to be related to Kanji lexical access. Because patient studies [10] suggest that Kanji characters are stored in the left posterior temporal cortex and an ERP study [11] suggested that the left posterior temporal ERP waveform reflects Kanji perception. Therefore we also examined this hypothesis.

II. Methods

A. Kanji discrimination task

The experimental task is depicted in Fig.1. In this task, the subjects were asked to discriminate Kanji characters from Hiragana characters presented on a PC monitor. (1) The subject clicked the left mouse button to start a trial. (2) Then a black screen was presented for a random delay (1.8-2.2s) and (3) either a Hiragana or Kanji image was presented briefly (83ms). (4) The subject had to report if the presented image was Hiragana or Kanji by clicking the left mouse button or not clicking it respectively. This brief presentation of an image is to prevent exploratory eye movements [3], because an eye movement is an artifact for ERP recording. The trial image order was pseudo-randomized. The images were presented in a 17 inch PC monitor located at 100cm away from the subject. Five subjects (23-35 years old) participated in this experiment.

We used a Kanji database which stores the known rates of Kanji characters examined by a linguistic study [12], and selected 600 characters from the most common Kanji characters which have 100% known rates in the database. The images of Hiragana characters were presented twice. Thus, the numbers of Kanji and Hiragana characters presented were 600 and 92 for each subject. Each character image was represented by the combination of the white lines on a black background, based on the MS Gothic font (16x16 points). The size of the images was $7.9^\circ \times 7.9^\circ$.

B. ERP recording

The electroencephalographies (EEGs) were recorded from 21 scalp electrodes (Fpz, Oz and 19 electrodes according to the international 10-20 system) with an electrocap (Electro-cap international). Fig.2(a) shows the electrode placements. A ground electrode was placed on the forehead. All scalp electrodes were referenced to linked earlobes. Simultaneously electro-oculograms (EOGs) were recorded from 2 electrodes one placed below the right eye and the other on the left outer canthus. The signals were amplified and 0.5-100Hz band-pass filtered by an amplifier (BIOTOP, NEC). The impedance of electrodes was kept under 10kΩ. The signals were stored into a PC with a 512Hz sampling rate. To reduce line noise, the signals were digitally low-pass filtered below 40Hz. For each electrode, the average voltage in the preceding 100ms interval before stimulus onset was used as the baseline in the trial. Trials containing 70μV EOG amplitude were removed from the subsequent analyses. For each electrode, a subject's single trial EEGs were taken from 100ms before to 500ms after stimulus onset in all correct trials, in which the subject behaviorally correctly discriminated characters presented. If necessary, we removed artifacts from those EEGs with ICA [11], [13], [14], [15]. A subject's ERPs were obtained by averaging the subject's single trial EEGs. The grand averaged ERPs were obtained by averaging ERPs across subjects.

III. Behavioral results

A prerequisite of ERP analysis is that the subjects behaviorally discriminated the presented characters while we were recording their EEGs. To examine this, we calculated the average correct rates across subjects for each character type. The average correct rates in Kanji and Hiragana character presented trials are 98.4%, and 99.2% respectively. These high correct rates suggest that the subjects carefully watched and correctly discriminated the presented characters. Therefore we conclude that measured ERPs can reflect the visual perception and discrimination processes for Kanji characters in the brain.

IV. ERP results

A. Grand averaged ERP waveforms

Fig.2(b) shows calculated grand averaged ERP waveforms at all electrodes. In each panel, we plotted the voltage at each time point separately for Kanji and Hiragana trials at each electrode. The abscissa is the time after stimulus onset and the ordinate is the voltage. The arrows indicate ERP components, P100, N170, P250, N320, VPP (Vertex Positive Potential), and P300. Those ERP components are known to appear to

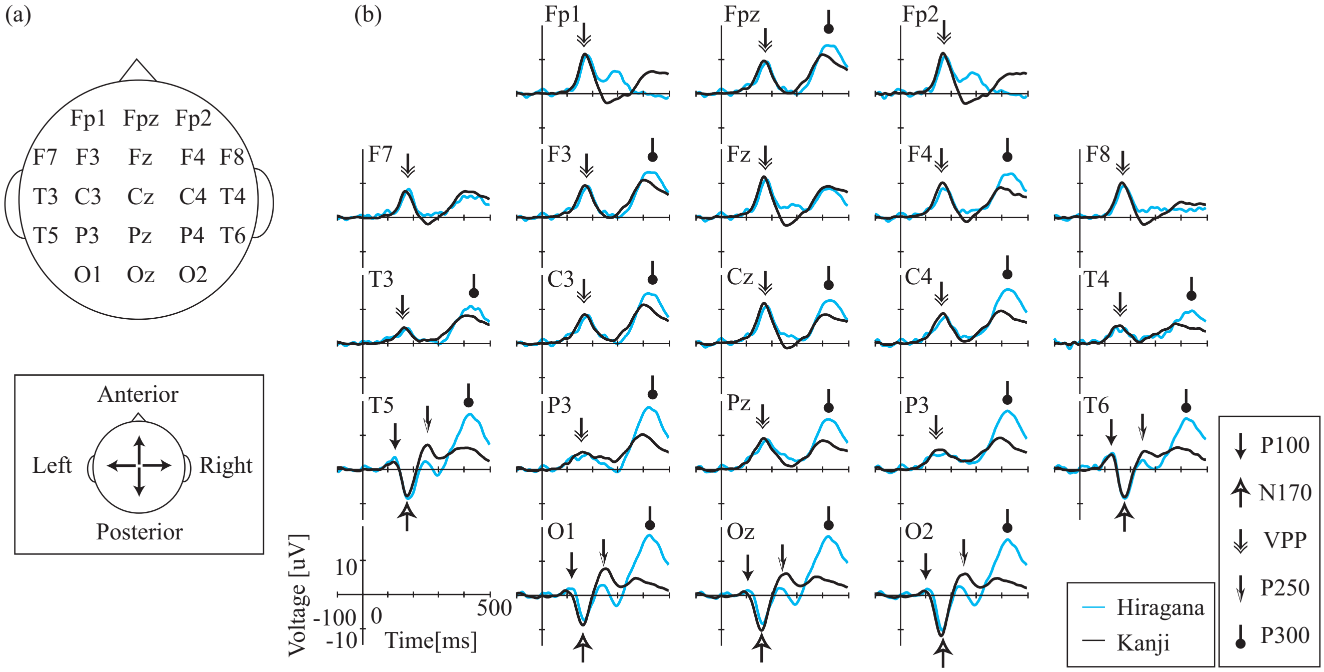

Fig. 2. (a) Electrode placement (b) Grand averaged ERP waveforms at all electrodes

presented words or single Kanji characters [9], [11], [16]. Therefore we conclude that the ERP waveforms were reliably measured while performing the task.

B. Frontal ERP waveforms

To examine the differences in the frontal ERP waveforms between Kanji and Hiragana trials, we calculated the difference waveforms by subtracting the grand averaged ERP waveforms of Kanji from those of Hiragana. As an example, Fig.3(a) shows the difference waveform at the frontal Fp2 electrode. The figure format is same as in Fig.2(b). A large difference appeared from around 170ms after stimulus onset.

To statistically examine the differences in the ERP waveform [3], we conducted a series of paired t-tests at each time point about the mean ERP amplitudes across subjects between Kanji and Hiragana trials. In Fig.3(b), we plotted the time course of t-scores and showed significant time periods. The horizontal broken lines indicate the significance level (p=0.05, $|t(4)|$=2.776) and the gray areas indicate the time periods with significant differences between Kanji and Hiragana trials. To determine the onset of differential activities between Kanji and Hiragana trials, we used a criterion used in the study [3] that is the onset is given by the fist time point followed by at least consecutive 15 significant time points. According to this criterion, the differential activity started from 217 ms after stimulus onset.

We conducted the same analysis for other frontal ERP waveforms and obtained similar results. To summarize the result, the significant time periods in the all frontal ERP waveforms are shown in Fig.4(a). The abscissa is the time after stimulus onset. The gray areas indicate the time periods with significant amplitude differences between Kanji and Hiragana trials. The differential activity started from 217ms after stimulus onset at the Fp1, Fp2, F8, Fz electrodes, Thus, these results support our first hypothesis. It suggests that the observed differences in the frontal ERP waveforms can be due to not only visual analysis but also lexical access for characters because of the time period.

In addition, we also found that, as can be seen from Fig.4(a), there were transient significant differences around 160ms after stimulus onset at the Fp2, F4, F7, Fz electrodes. Because this time period is before lexical access occurs [7], [8] and after Kanji perception occurs in visual areas (around 130ms after stimulus onset in the T5 and Oz electrodes) [11], activities in the frontal area in this time period may be related to Kanji perception or a discrimination process based on the perception.

C. Left posterior temporal ERP waveforms

Next, we examined the second hypothesis that the difference in the frontal ERP waveforms coincidentally appears with that in the left posterior temporal ERP waveforms, which seems to be related to Kanji lexical access.

Fig.3(c) shows the difference waveform between Kanji and Hiragana trials at the left posterior temporal T5 electrode. As can be seen, there were two peaks: a small peak around 130ms and a big peak around 280ms after stimulus onset.

With the previous procedures, we statistically analyzed the difference in the ERP waveforms. The time course of t-scores and significant time periods are shown in Fig.3(d). The figure format is same as in Fig.3(b). As can be seen, the time periods around the two peaks were significant. The first significant time period during 121-143ms (12 time points) corresponds to the time period where an ERP study [11] reported in relation to Kanji perception.

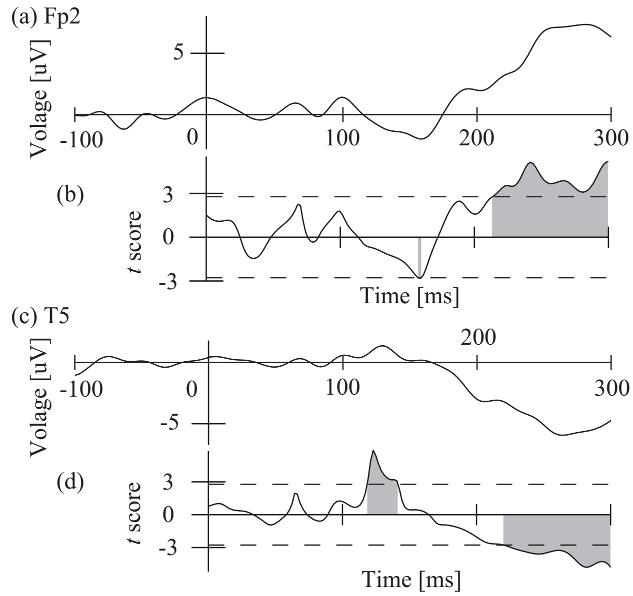

Fig. 3. Difference waveforms and t-score time courses at the (a) Fp2 and (b) T5 electrodes

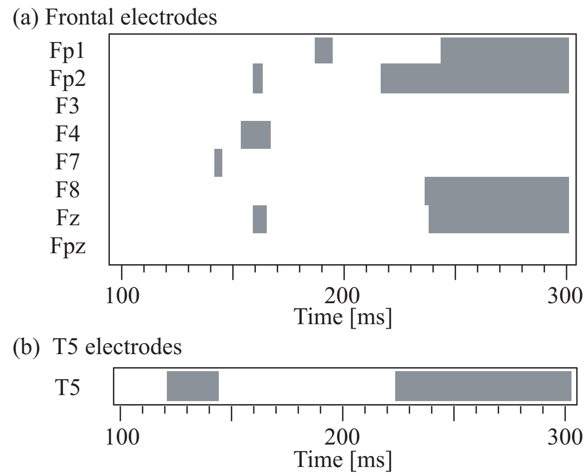

Fig. 4. Periods with the significant ERP amplitude differences between Kanji and Hiragana trials

According to the criterion about the onset of differential activities [3], the differential activity started from 223ms after stimulus onset. Significant time periods in the T5 ERP waveform is summarized in Fig.4(b). As can be seen, the significant differences in the frontal ERP waveforms from around 220ms after stimulus onset almost coincidentally appear with that in the T5 ERP waveform. Thus, this result supports the second hypothesis.

V. Conclusion

In Kanji character discrimination, we hypothesized that (1) the frontal ERP waveforms reflect the discrimination process from 200-250ms after stimulus onset and that (2) the discrimination process in the frontal ERP waveforms coincidentally appears with that in the left posterior temporal ERP waveform, which seems to be related to Kanji lexical access. To examine these hypotheses, we recorded and analyzed ERPs while performing a Kanji discrimination task where the subjects had to discriminate between Kanji and Hiragana characters.

(1) The frontal ERP waveforms showed significant differences from 217ms after stimulus onset between Kanji and Hiragana trials. (2) The left posterior temporal ERP waveform also showed a significant difference from 223ms after stimulus onset.

These results supported our hypotheses. Therefore we suggest that, in Kanji character discrimination, lexical access for Kanji characters in the left posterior temporal area is related to the discrimination process in the frontal area. Also, we found that the frontal ERP waveforms around 160ms after stimulus onset may be related to Kanji perception or a discrimination process based on the perception.

In future studies, ERPs between when lexical access is involved and when it isn't should be directly compared in the same task. And it is also necessary to study Kanji character processing in word and sentence levels.

References

[1] M.S. Gazzaniga, R.B. Ivry, and G.R. Mangun, "Cognitive Neuroscience," W.W. Norton & Company, Newyork, 1998.
[2] H. Gemba, and K. Sasaki, "Potential related to no-go reaction of go/no-go hand movement task with color discrimination in human," *Neurosci. Lett.*, vol. 101, pp. 263-268, 1989.
[3] S. Thorpe, D. Fize, and C. Marlot, "Speed of Processing in the Human Visual System," *Nature,* vol. 381, pp. 520-527, 1996.
[4] R. VanRullen, and S.J. Thorpe, "The time course of visual processing: from early perception to decision-making," *J. Cogn. Neurosci.,* vol. 13, pp.454-461, 2001.
[5] R. VanRullen, and S.J.Thorpe, "Is it a bird? Is it a plane? Ultra-rapid visual categorisation of natural and artifactual objects," *Perception,* vol. 30, pp. 655-668, 2001.
[6] S. Dehaene, L. Cohen, M. Sigman, and F. Vinckier, "The neural code for written words: a proposal," *Trends Cogn. Sci.,* vol. 9, pp. 335-341, 2005.
[7] A.P. Rudell, "Rapid stream stimulation and the recognition potential," *Electroencephalogr. Clin. Neurophysiol.* vol. 83, pp. 77-82, 1992.
[8] M. Martin-Loeches, J.A. Hinojosa, G. Gomez-Jarabo, and F.J. Rubia, "The recognition potential: an erp index of lexical access," *Brain and Language,* vol. 70, pp. 364-384, 1999.
[9] M. Hayashi, Y. Kayamoto, H. Tanaka, and J. Yamada, "Semantic activation by japanese kanji: evidence from event-related potentials," *Perceptural and Motor Skills,* vol. 86, pp. 375-382, 1998.
[10] M. Iwata, "Kanji versus kana neuropsychological correlates of the japanese writing system," *Trends Neurosci.,* vol. 7, pp. 290-293, 1984.
[11] H. Abe and M. Nakayama, "Event-related potential study of kanji perception process," *J. Inst. Image Inf. Television Eng.,* vol. 60, pp. 397-404, 2006.
[12] N. Amano and K. Kondo (ed.), "Moji Tokusei (Character charasteristics)," Tokyo: Sanseido, 1999.
[13] S. Makeig, M. Westerfield, T.P. Jung, J. Covington, J. Townsend and T.J. Sejnowski, and E. Courchesne, "Functionally Independent Components of the Late Positive Event-related Potential during Visual Spatial Attention," *J. of Neurosci.,* vol. 19, pp. 2665-2680, 1999.
[14] T.P. Jung, S. Makeig, C. Humphries, T.W. Lee, M.J. McKeown, V. Iragui, and T.J. Sejnowski, "Removing electroencephalographic artifacts by blind source separation," *Psychophysiol.,* vol. 37, pp. 163-178, 2000.
[15] A. Delorme and S. Makeig, "An Open Source Toolbox for analysis of single-trial EEG dynamics," *J. of Neurosci. Method,* vol. 134, pp. 9-21, 2004.
[16] B. Rossion, C.A. Joyce, G.W. Cottrell, and M.J. Tarr, "Early lateralization and orientation tuning for face, word, and object processing in the visual cortex," *Neuroimage,* vol. 20, pp. 1609-1624, 2003.